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NASA DC-8 AIRBORNE SCANNING LIDAR CLOUD AND CONTRAIL OBSERVATIONS

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ABSTRACT

An angular scanning backscatter lidar has been developed and operated from the NASA DC-8 aircraft; the lidar viewing direction could be scanned from vertically upward to forward in the direction of aircraft travel to vertically downward. The scanning lidar was used to generate real-time video displays of clouds and contrails above, below, and ahead of the aircraft to aid in positioning the aircraft for achieving optimum cloud/contrail sampling by onboard in situ samplers. Data examples show that the lidar provides unique information for the interpretation of the other data records and that combined data analyses provides enhanced evaluations of contrail/cloud structure, dynamics, composition, and optical/ radiative properties.

1. INTRODUCTION

The environmental consequences of subsonic and supersonic aircraft fleets need better definition for input to the development of future aircraft and their operational scenarios. NASA is developing a capability to predict the effects of current and future aircraft on the environment through a 3-D model consisting of modular parameterizations of effluent emissions and their microphysical and chemical transformations, dynamic behavior, and radiation budget perturbations. Experimental data are needed to better understand relevant atmospheric processes and to develop quantitative relationships that improve the 3-D model performance. Model analyses will be used to assess and report the effects of aviation on the environment.

As part of the atmospheric effects of aviation project (AEAP), NASA formulated an extensive multi-aircraft field program, termed the subsonic aircraft: contrail and cloud effects special study (SUCCESS), that was conducted during April and May 1996. In addition to many advanced and recently developed atmospheric sensors, an angular scanning lidar was installed on the NASA DC-8 research aircraft and operated in support of SUCCESS.

2. LIDAR SYSTEM

The DC-8 scanning lidar employed a conventional two-wavelength (1.064 and 0.532 μm) 35-cm telescope system that previously had been used for both ground-based and airborne operations. The major effort in the DC-8 installation was the development of a scanning capability that provided for observations in the manner shown by Figure 1. Basically, a pressurized motor driven and computer controlled rotating cylinder that contained a 45 degree optical mirror and a 43-cm diameter window was attached to the DC-8 fuselage. Figure 2 pictures the scanning mirror pod along with an aerodynamic fairing located to the rear of the pod. The lidar was installed near the rear of the aircraft as the forward sections were needed for installation of in situ chemical, aerosol, radiation and meteorological sensors. Details of the lidar installation have been presented by Nielsen et al.[1]

3. LIDAR OPERATIONS

The primary purpose of the DC-8 scanning lidar was to locate and help direct the aircraft into low density aircraft contrails and cirrus clouds so that they could be sampled by onboard in situ sensors. Lidar backscatter signatures were processed for real-time pictorial display on the DC-8 NTSC video network for viewing by the flight crew and experimenters to help guide flight direction and data collection operations. The digital signatures were also stored on 8-mm Exabyte tape for use in subsequent data analyses programs.

The lidar was normally operated at vertical up or down viewing angles to establish the presence and location of backscattering layers above and below the aircraft. At sampling altitudes the lidar was operated in forward viewing angular scan patterns to map the vertical structure of cirrus and contrails ahead of the aircraft. Figure 3 presents examples of the real-time angular scan display as presented on the DC-8 video network. The intensity modulated display presents a picture of cloud structure with a vertical axis of 1000 ft per division and a horizontal axis of 15 km. The backscatter signature for the last laser firing was plotted below the picture display and text information was given below the signature plot. The laser was fired at a rate of 10 Hz and the scanning mirror was rotated at 1° per second. The starting, ending, and incremental angles as well as the scan rate were computer controlled and easily adjusted by thumb switches.

4. LIDAR DATA EXAMPLES

Figure 4 presents DC-8 lidar data collected on 12 May 1996 with the lidar viewing in a fixed downward direction while the DC-8 was sampling its own contrail generated during an earlier flight over the area. The lidar display clearly depicts times when the contrail is below the aircraft and indicates times when the aircraft penetrated the contrail. These times agree well with times of observed increased water content and NO_y concentrations measured by onboard in situ sensors. The data are well correlated although the water content and NO_y sampling inlets were located on different sides of the DC-8. The combined lidar and in situ observations established times the contrail was above the aircraft as indicated in Figure 4. Onboard radiometric observations agree with this analysis showing cooler IR "surface" temperature and increased upwelling solar flux at times when the contrail was below the aircraft. Although the solar radiometric data have not yet been calibrated or corrected for aircraft motions, it appears that the albedo above the contrail is increased about 30% by the presence of the contrail.

Figure 5 presents angular scan data of DC-8 effluent plume cross sections (plotted with elevation angle and distance from aircraft axes) as the DC-8 closed the distance on its own contrail generated during the first flight of the system on 10 April 1996. The first six contrail cross sections are presented for a wavelength of 0.532 µm and the last cross section is presented for a wavelength of 1.064 µm. The onboard in situ chemical sensors detected the effluent plume at 00:53:03 GMT, the same time as the aircraft penetrated the contrail as inferred by the lidar data..

On 10 May 1996, during DC-8 transport from Salina, Kansas, to Ames Research Center, California, the lidar observed a widespread thin scattering layer at an altitude of about 43,000 ft MSL—above the flight ceiling of the DC-8 during this flight. Figure 6 presents upward-viewing lidar data showing backscatter returns from the layer before and after an aircraft turn that was made at an aircraft altitude of about 17,000 ft MSL. The backscatter from the particulate layer sharply decreases as the aircraft turn is initiated and the laser pulses intersected the layer at non-vertical angles. This behavior has been observed for high-altitude tropical cirrus clouds consisting of horizontally aligned plate-shaped ice crystals[2] and has been observed by several other lidar researchers.[3,4] The rate the backscatter decreases with angle is dependent on size, shape, and orientation of the crystals.[5] The scanning lidar provides a means to measure the zenith-enhanced backscatter without aircraft turns that affect other measurements such as solar and infrared flux. The horizontal alignment has been explained by falling crystals orienting themselves to offer maximum resistance to motion.[5] Other DC-8 scanning lidar data show intense single-pixel lidar returns probably from individual precipitating ice crystals from aircraft contrails.[6]

5. DoD APPLICATIONS

The DC-8 scanning lidar concept can be readily deployed on DoD transport size aircraft (e.g., ABL, AST, ARGUS, Cobra Ball, etc.). Applications include the following:

- Detection and optical characterization of particulate layers above aircraft ceilings.
- Evaluation of high-altitude cirrus cloud and aircraft emissions on performance of airborne multispectral radiometers and infrared search and track (IRST) sensors, atmospheric propagation of high energy laser beams, and ablation of objects reentering from space.

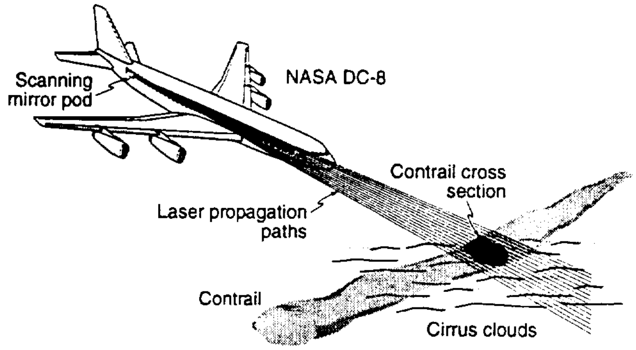

Figure 1. DC-8 scanning lidar illustration.

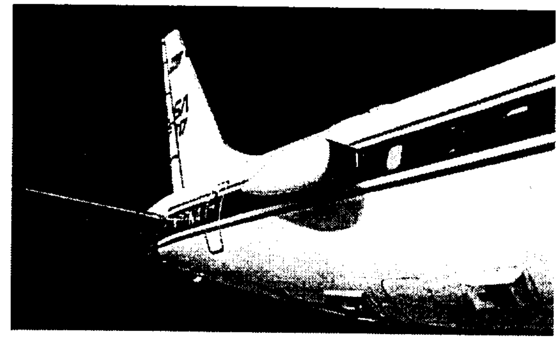

Figure 2. DC-8 scanning lidar pod and aerodynamic fairing installation with pod positioned for forward lidar viewing.

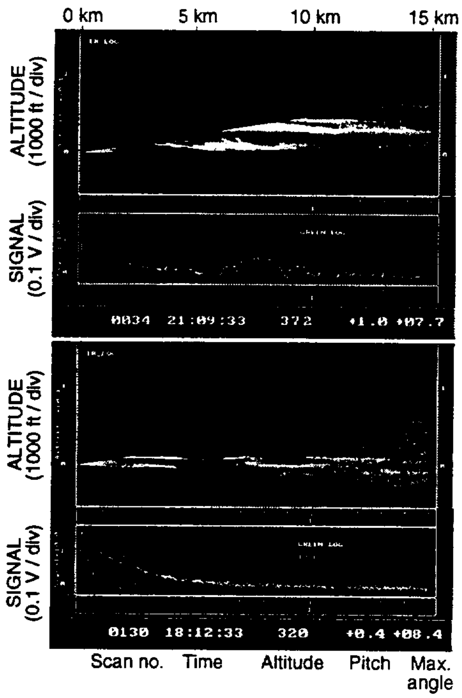

Figure 3. Real-time angular scan video displays generated by the DC-8 scanning lidar system.

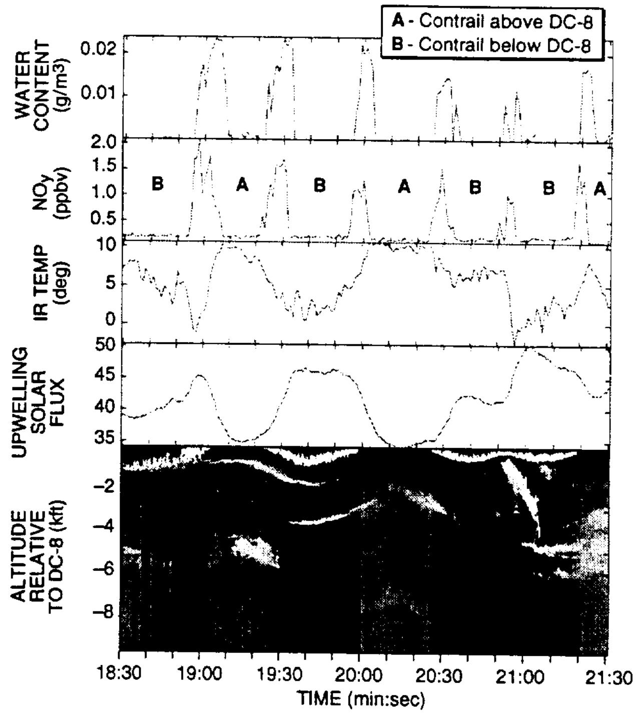

Figure 4. Lidar and selected in situ and radiometric data at times of the DC-8 penetrating its earlier generated contrail, 12 May 1996, 23:18:30 to 23:21:30 GMT. DC-8 altitude approximately 36 kft.

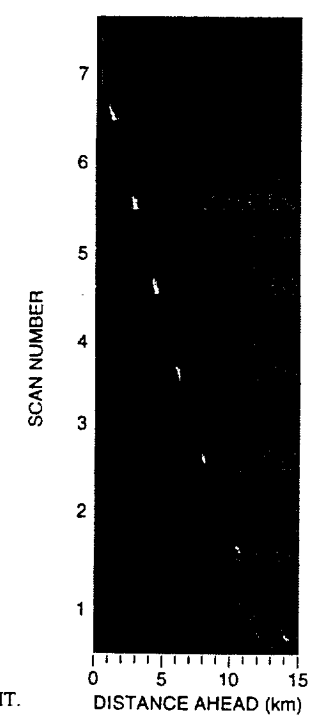

Figure 5. DC-8 lidar forward-viewing scan observations as the aircraft approaches a contrail generated earlier by the DC-8. Data are plotted with a vertical axis of time (scan angle) and a horizontal axis of distance ahead of the DC-8. 11 April 1996, 00:49:21 to 00:50:50 GMT.

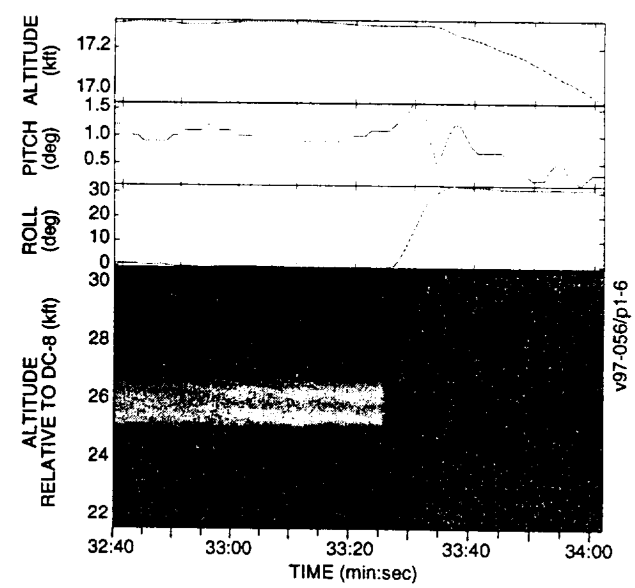

Figure 6. DC-8 lidar observations and selected DC-8 flight parameters showing a sharp decrease in lidar backscatter from a high altitude (43 kft) layer at small angles from the vertical, 10 May 1996, 16:32:40 to 16:34:05 GMT.

- Mapping visible and subvisible cirrus cloud distributions to help position aircraft to minimize atmospheric effects on DoD sensors and operations.
- Tracking aircraft effluents (engine exhaust, laser gases, etc.) to help position aircraft and sensor viewing angles to minimize effluent effects on onboard optical standoff and in situ sensors.
- Inferring atmospheric chemical composition and turbulent properties that can affect standoff sensor performance employing elastic backscatter lidar techniques.

6. ACKNOWLEDGMENTS

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7. REFERENCES

1. Nielsen, N. B. et al., "NASA DC-8 Airborne Scanning Lidar Sensor Development," Proceedings of the Second International Airborne Remote Sensing Conference and Exhibition, San Francisco, CA, 24-27 June 1996.

2. Uthe, E. E., and P. B. Russell, "Lidar Observations at Tropical High-Altitude Cirrus Clouds," in *Radiation in the Armosphere,* H. J. Bolle, ed., Science Press, Princeton, New Jersey, 1976.

3. Intrieri, J. M. et al., "Multiwavelength Observations of a Developing Cloud System: The FIRE II 26 November 1991 Core Study," *J. Atmos. Sci.,* 4079-4093, 1995.

4. Thomas, L. et al., "Lidar Observations of the Horizontal Orientation of Ice Crystals in Cirrus Clouds," *Tellus.* 211-216, 1990.

5. Platt, C. M. R., "Lidar Backscatter From Horizontal Ice Crystal Plates," *J. Appl. Meteor.,* 482–488, 1978.

6. Uthe, E. E., N. B. Nielsen, and T. E. Oseberg, "DC-8 Scanning Lidar Applications During SUCCESS," submitted to *Geophysical Research Letters,* June 1997.

7. Gerber, H. et al., "Measurement of Wave Cloud Microphysics With Two New Aircraft Probes," submitted to *Geophyscial Research Letters,* June 1997.

8 Ridley, B. A. et al., "Distributions of NO, No_x, No_y, and O_3 to 12 km Altitude During the Summer Monsoon Season Over New Mexico," *J. Geophys. Res.,*99, 25519-25534, 1994.

9. Valero, F. P. J. et al., "The Atmospheric Radiation Measurements Enhanced Shortwave Experiment (ARESE): Experimental and Data Details," submitted to *J. Geophys. Res.,* 1997.